

What About When Sub-Slab Depressurization Doesn't Work Well

Southern Research Inst., Birmingham, AL

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# NOTICE

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| 16. ABSTRACT The paper discusses the mitigation of radon levels in basement houses when sub-slab depressurization (SSD), a widely used mitigation technique, is not a viable option. For example, in some houses the slab is poured directly on the soil, resulting in poor-to-nonexistent communication under the slab. To apply SSD requires elaborate plumbing and multiple suction holes in the slab. To develop viable alternatives, EPA has funded research to explore other radon mitigation options. Case studies include: basement pressurization with and without heat extraction, and filtration using charcoal. In the first, air from the upper portion of the house was forced into the basement, producing a pressure barrier at the slab/soil interface. In one house, heat was extracted from the upstairs using a heat pump to supply hot water for the occupants. In the second, a bed of charcoal was used to remove the radon gas. The charcoal bed was flushed with outdoor air to extract the radon before its complete decay to radon daughters. |    |                                                                                      |                        |
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| Heat Pumps                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |    |                                                                                      |                        |
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ABSTRACT

While the sub-slab depressurization (SSD) technique is widely used to mitigate basement houses, there are instances for which this method is not a viable option. For example, in some houses the slab is poured directly on the soil, resulting in poor-to-nonexistent communication under the slab. To apply SSD methods requires elaborate plumbing and multiple suction holes in the slab. In an effort to develop viable alternatives, EPA has funded research to explore other radon mitigation options. Case studies will be presented that include: basement pressurization with and without heat extraction, and filtration using charcoal. In the first, air from the upper portion of the house was forced into the basement, producing a pressure barrier at the slab/soil interface. In one case the heat was extracted from the upstairs air using a heat pump device to supply hot water for the occupants. The air filtration method used a bed of charcoal to remove the radon gas. The charcoal bed was flushed with outdoor air to extract the radon before complete decay to radon daughters took place.

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## INTRODUCTION

In Phase I of this EPA Radon Mitigation Demonstration many of the basement houses were identified which had poor sub-slab communications. In attempting to implement a sub-slab depressurization (SSD) system in houses such as these, special attention had to be taken to ensure adequate coverage of the possible radon entry areas in the basement. In an effort to determine if less expensive techniques were available that might have a higher probability of success, the mitigation methods described below were investigated. These techniques may be applicable in other areas such as Central Florida where the lack of communication under the slab increases the complexity of SSD systems.

## DESCRIPTION OF HOUSES

Nine houses were selected for the Phase II demonstration in Nashville, TN. Of these, six are basement houses and three are crawl space houses. Of the six basement houses only four have been mitigated as of this paper. A brief description of these four houses follows.

DW 01 is a one story frame house with brick veneer upstairs. The basement is a daylight walkout at the back of the house with walls of concrete block. The basement area is approximately 70% finished with a bedroom and den in the front (below-grade) part of the basement and an unfinished laundry room and workshop at the rear. The heating system for the house includes a central heat pump which is seldom used and two wood stoves, one upstairs and one in the finished basement. There are no other combustion appliances in the house. Measurement last winter in the basement showed the radon level to be 21.4 pCi/L.\* Results of infiltration measurements gave a basement air changes per hour (ACH) value of 2 hr<sup>-1</sup> at 4 Pa and a whole house ACH value of 1.4 hr<sup>-1</sup> at 4 Pa.

DW 35 is a two story frame house with brick veneer on the exterior. The basement is almost totally below grade with walls of cut stone. The basement is in a semi-finished state but unused because of water problems. A central gas fired furnace is located in the basement with numerous leaky joints that appear to have once been sealed with asbestos tape. Also located in the basement are a gas fired clothes dryer and water heater. Visual inspection showed numerous thermal bypasses from the basement to upstairs. A seldom-to-never-used fireplace is located in one room of the basement. The flue has been closed loosely with sheet metal but still shows air exfiltration. A previous radon measurement in the basement was 18 pCi/L. Infiltration measurements showed that the basement was very leaky with an ACH of 6.3 hr<sup>-1</sup>, and whole house ACH of 4.4 hr<sup>-1</sup> at 4 Pa.

DW 38 is a one story brick veneer house with a walkout daylight basement. The walls of the basement are concrete block with three of the walls about half below-grade by about 3-4 ft (91-122 cm). The basement is 50% finished with a den in one part and a laundry room and workshop in the other. The heating and air-conditioning (HAC) system is a central unit in the basement (heat pump) with very leaky ductwork (both supply and return). There were no combustion

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\*1 pCi/L = 37 Bq/m<sup>3</sup>

appliances in the basement. Previous measurements in this house were no combustion appliance in the basement. Previous measurements in this house were 11.1 pCi/L in the basement. Infiltration measurements resulted in basement ACH values of  $2.8 \text{ hr}^{-1}$  and  $1.6 \text{ hr}^{-1}$  for the whole house (at 4 Pa).

DW 47 is a single story frame/brick veneer house with a walkout basement. The homeowner was in the process of finishing the basement when mitigation was undertaken. The walls of the basement are of concrete block with three sides below grade. The house is total electric with the air handler located upstairs. The basement contained a roughed-out opening for a fireplace with a large amount of bypass area to the upstairs flue box. Also located in the basement is a heat pump water heater using basement heat. Previous measurements by the homeowner were 13.1 and 16.9 pCi/L upstairs and 21.1 pCi/L in the basement. Infiltration measurements gave ACH values of  $2.4 \text{ hr}^{-1}$  for the basement alone and  $1.3 \text{ hr}^{-1}$  for the whole house (at 4 Pa).

#### MITIGATION SYSTEMS

In three of the houses (DW 01, DW 38, and DW 47), the radon levels were mitigated by pressurizing the basement with air withdrawn from upstairs. This was done in two of the houses (DW 01 and DW 38) by using an in-line blower with maximum flow capability of approximately 400 cfm at 0 in. of water ( $0.189 \text{ m}^3/\text{s}$  at 0 Pa) gauge (T3A Turbo 8, R. B. Kanalflokt, Inc., Sarasota, FL). In DW 01 the air inlet was located in the central hallway of the house and in DW 38 it was located in the floor of the kitchen.

In the remaining house (DW 47), a heat pump water heater device (HPV-80 Therma-Vent™, Therma-Stor Products Group, DEC International, Inc., Madison, WI) was used that withdrew air from the upstairs area down through the heat pump and then exhausted the air into the basement. The heat extracted from the air was used to provide hot water for the homeowner. In DW 47 the air inlet was located in the central hallway.

Several parameters of each of these three houses were monitored and recorded using a datalogging device. The parameters were: air temperatures upstairs, in the basement, and outdoors; air pressure differentials between the basement and upstairs, between the basement and outdoors, and between the basement and the sub-slab region; wind speed and direction; rainfall amounts; HAV operation; and continuous radon levels both in the basement and in the living area upstairs. The monitoring period was quite long, ranging from several weeks to months.

Several major points were addressed for this type of mitigation system. How much sealing is required in the basement to achieve sufficient overpressurization while keeping the air flow rate down to less than 300-400 cfm ( $0.142\text{-}0.189 \text{ m}^3/\text{s}$ )? The effects of such a system on the ACH of the house will also be measured in order to determine how much of an energy penalty the system imposes on the house.

In the remaining basement house (DW 35) an off-the-shelf activated charcoal air cleaning unit (Radsorb-222, RAD Systems, Inc., Westborough, MA) was used to remove the radon gas from the basement air. In this device the radon gas

absorbed by the charcoal is removed by reverse flushing to the outdoors before the radon completely decays to its daughter products and remains trapped in the charcoal bed. The radon levels in both the basement and the living area upstairs were continuously monitored over a period of several months.

#### HOUSE MITIGATION RESULTS

These houses were mitigated during 1989. Because of the length of monitoring time, the mitigations extended from January through November. Prior to mitigation, long term alpha track detectors (ATDs) were installed in the houses. The results of these pre-mitigation measurements are shown in Table 1. The radon levels in the basements ranged from 9.4 to 24.4 pCi/L and the levels on the first floor ranged from 4.9 to 10.4 pCi/L. Short term (3 day) charcoal canister (CC) measurements were carried out just prior to mitigation. These results are shown in Table 2. The agreements between the ATD results and the CC values are not as good as might be expected. The differences are attributed to differences in the time of year and to weather differences. The average levels in the basement and in the living area for both the CC and the ATD measurements are summarized in Figure 1.

##### House DW 47

The first house to be mitigated was DW 47 using the HPV-80 device. The radon levels in the basement and in the living room upstairs along with the house parameters were continuously monitored beginning on 1/31/89. The continuous radon monitor (CRM) values during the pre-mitigation period averaged 13.1 pCi/L in the living room and 18.1 pCi/L in the basement. The HPV-80 device was installed on 3/15/89, and the openings between the basement and upstairs were sealed the following day. The major openings that were closed were the bypass to the chimney flue, the water and sewer pipe penetrations, and an opening in the sub-floor below the HAC. Since the basement was largely unfinished, sealing these openings was simple and effective. The HPV-80 fan was turned on at 6:40 pm on 3/15/89. The radon levels began to decline within 6 hours, and within 12 hours the levels were less than 2 pCi/L in both the basement and the living room. The CRMs remained in the house until 4/13/89. Over this post-mitigation period the average radon levels in the basement were 1.8 and 1.7 pCi/L in the living room.

Prior to turning the HPV-80 device on, the basement pressure was averaging about 2.5 Pa below ambient outdoor pressure. With the system on, the basement pressure was approximately 2.5 Pa above ambient outdoor pressure. The HPV device flowrate was 141 cfm (0.067 m<sup>3</sup>/s) as measured at the exhaust outlet in the basement. On 4/4/89 the HPV-80 device was shut down for approximately 48 hours and then was turned back on. The resultant pressure changes over this period are shown in Figure 2, and the changes in the radon levels are shown in Figure 3. During the time the HPV-80 device was on, the sub-slab pressure was averaging about 2 Pa above the basement pressure, and the basement was about 2.5 Pa above the outdoor pressure. With the HPV-80 device off, the sub-slab pressure decreased to 1 Pa or less, and the basement pressure decreased to about -3 Pa relative to the outdoors. The radon levels in both the basement and in the living room increased by a factors of 5 or more. When the system was turned back on, the levels decreased sharply as seen in Figure 3. Overall the reduction in

radon levels was approximately 92% in the basement and 83% in the living room.

#### House DW 38

The second house to be mitigated using basement pressurization was DW 38. In this house an in-line duct fan was used to pull air from the kitchen upstairs. The air was then distributed in the basement in two zones, the finished den and the unfinished workshop. The mitigation system was installed and energized on 4/25/89. Prior to mitigation, the radon levels and house parameters were monitored beginning on 4/13/89. The average pre-mitigation radon levels measured with the CRMs were 10.6 pCi/L in the living room and 14.6 pCi/L in the basement. Also over this period, the average basement pressure was approximately 1 to 2 Pa below the outdoor ambient pressure, and the sub-slab area pressure was approximately 2 Pa more positive than the basement. During the initial mitigation a small fan (158 cfm at 0 in. water gauge -- 0.0746 m<sup>3</sup>/s at 0 Pa -- model R125, Fantech, Inc., Sarasota, FL) was used. It was soon apparent that the fan could not supply sufficient air flow to overcome the leaks to the upstairs and to the outdoors. A larger fan was installed (410 cfm at 0 in. water gauge -- 0.193 m<sup>3</sup>/s at 0 Pa -- model T3A Turbo 8, R. B. Kanalfakt, Inc., Sarasota, FL) to pressurize the basement.

Sealing in this house was difficult because of limited access to the overhead from the basement. The finished basement ceiling had acoustic tile attached directly to the floor joists. Also, the homeowner had made several changes in the electrical and plumbing systems over the years and consequently left many openings. The HAC system located in the unfinished part of the basement had not only many leaks in the cold air return but also a return vent in the finished area of the basement that had to be sealed off. To prevent the pressurization air from leaking back upstairs through the return duct, a back-draft damper was constructed at the return opening upstairs. Also, to prevent back-flow through the supply vents in the basement, back-draft flaps of vinyl were attached to the outside of the supply grills. A direct path to the attic in the basement stairwell also required sealing. In summary, this house was extremely difficult to seal. The basement and the upstairs were never completely isolated.

Following installation of the larger pressurization fan and sealing of as many of the openings as possible, the pressure difference between the basement and the sub-slab region was on the average reduced to zero. The basement was never pressurized above the outdoor ambient conditions. However, achieving a neutral pressure difference relative to the sub-slab significantly reduced radon gas flow into the basement. The radon levels in the basement, as measured with the CRM, averaged 1.3 pCi/L. These levels were confirmed with CC measurements carried out on 8/22-24/89. The CC results as shown in Table 2 were 1.2 pCi/L in the basement and 0.9 pCi/L in the living room upstairs.

#### House DW 01

This house was mitigated over the period from 10/2/89 to 10/6/89. Prior to mitigation the datalogging system was installed on 9/13/89 and remained until 11/6/89. The pre-mitigation radon levels in this house were 19.5 pCi/L in the

basement and 9.8 pCi/L in the living room as measured with CCs and shown in Table 2. The average radon levels recorded with the CRMs (model R210F radon monitor, Femto-Tech, Inc., Carlisle, OH) were 22.5 pCi/L in the basement and 8.5 pCi/L in the living room. The mitigation system was installed and turned on at approximately 4 pm on 10/3/89. Sealing of the basement openings to the upstairs and to the outdoors was delayed until 10/4/89. With only the pressurization fan installed and no additional sealing, the radon levels dropped within 6 hours to 2.8 pCi/L upstairs and 4.2 pCi/L in the basement. This is shown in Figure 4. The average pressure in the basement relative to: the outdoors changed from -0.4 to -0.2 Pa, the upstairs from +0.03 to +2.30 Pa, and the sub-slab area from -0.1 Pa to zero. With a limited amount of sealing the radon levels dropped further to 1.6 pCi/L upstairs and 1.9 pCi/L in the basement. The average pressures in the basement increased to +1.1 Pa relative to the outdoors, +2.4 Pa above the upstairs, and -0.14 Pa above that under the slab.

On one occasion, the homeowner inadvertently left the door between the upstairs and basement open for much of a day. During this time pressurization was lost in the basement and the radon levels in both the basement and the living room increased sharply. These results are shown in Figures 5 and 6, respectively.

The radon levels and the house parameters were monitored until 11/6/89. The radon levels in the basement averaged 1.2 pCi/L and in the living room 1.1 pCi/L. These levels were confirmed with CC measurements carried out over the period 11/6-8/89. These tests gave the results (shown in Table 2) of 0.2 pCi/L in the basement and upstairs.

#### House DW 35

This house was mitigated with the charcoal adsorption unit (Radsorb-222). The unit was installed on 5/30/89. Continuous radon monitors (model R210F radon monitor, Femto-Tech, Inc., Carlisle, OH) were installed prior to installation on 5/18/89. Pre-mitigation radon levels in the basement averaged 11.2 pCi/L and 5.4 pCi/L in the living room upstairs. The charcoal adsorption unit was operated more-or-less continually for the next 6 months. Monitoring of the radon levels in the basement and upstairs continued throughout most of this period. Monitoring was interrupted on several occasions by failure of the CRMs. The failures were due to the excessive moisture levels in the basement. Over the last period for which data were available for this paper, the average levels measured by CRMs (model AB5 with PRD1 passive cells, Pylon Electronics Development Co., Inc., Ottawa, Canada) were 5.5 pCi/L in the basement and 4.2 pCi/L upstairs. The CRMs also indicate that during heavy rains the levels can increase drastically. During one such rain storm on 10/17/89 the levels increased to about 54 pCi/L in the basement and 25 pCi/L upstairs. Following the rain storm, the charcoal device reduced the levels to 6.4 pCi/L in the basement and 3.5 pCi/L upstairs within 24 hours. The radon levels in both the basement and the living area over this period are shown in Figure 7.

Post-mitigation CC measurements were carried out over the period 11/6-8/89 as shown in Table 2. These levels are higher than those measured with the CRMs over a much longer period. However, the CC measurements were begun shortly (about 6 hours) after a storm dropped approximately 1.2 in. (3 cm) of rain in

the area. CRMs will be used to follow this house for some additional period of time. Also, long term ATDs have been installed both in the basement and upstairs.

#### CONCLUSIONS

The basement pressurization technique has been applied to three houses of differing age and construction types. In one house heat was extracted from the upstairs air before pressurizing the basement. The degree of success in reducing the radon levels with this method is determined by how airtight the basement can be made to the outdoors and to the upstairs. For houses in which the HAC system incorporates continuous ductwork in good condition, sealing is not too difficult. For houses in which the floor joists are used as the sides of cold air return ducts, sealing can be very difficult and time consuming. Each house has to be evaluated on its own. Use of diagnostic tests such as blower door measurements can aid in the evaluation prior to mitigation system design. The charcoal adsorption technique is currently under test in one house. The device is capable of reducing moderate levels (10 to 15 pCi/L) of radon to levels that approach 4 pCi/L. However, the device cannot control rapidly increasing levels as produced during water capping of the surrounding soils. The long-term effectiveness of the device is currently under study.

Table 1. Alpha Track Detector Measurements for  
Nashville Phase II Basement Houses

| <u>Location<br/>Code</u> | <u>Install<br/>Date</u> | <u>Remove<br/>Date</u> | <u>Days<br/>Exposure</u> | <u>Radon<br/>Level*</u> | <u>Comments</u> |
|--------------------------|-------------------------|------------------------|--------------------------|-------------------------|-----------------|
| DW 01-B <sup>a</sup>     | 09/22/88                | 09/14/89               | 357                      | 12.6                    | Pre-Mitigation  |
| DW 01-B                  | 09/22/88                | 09/14/89               | 357                      | 16.2                    | Pre-Mitigation  |
| DW 01-L                  | 09/22/88                | 09/14/89               | 357                      | 5.4                     | Pre-Mitigation  |
| DW 01-L                  | 09/22/88                | 09/14/89               | 357                      | 5.0                     | Pre-Mitigation  |
| DW 35-B                  | 09/20/88                | 05/30/89               | 252                      | 9.4                     | Pre-Mitigation  |
| DW 35-B                  | 09/20/88                | 05/30/89               | 252                      | 9.6                     | Pre-Mitigation  |
| DW 35-L                  | 09/20/88                | 05/30/89               | 252                      | 5.4                     | Pre-Mitigation  |
| DW 35-L                  | 09/20/88                | 05/30/89               | 252                      | 4.9                     | Pre-Mitigation  |
| DW 38-B                  | 09/21/88                | 05/04/89               | 225                      | 11.1                    | Pre-Mitigation  |
| DW 38-B                  | 09/21/88                | 05/04/89               | 225                      | 11.2                    | Pre-Mitigation  |
| DW 38-L                  | 09/21/88                | 05/04/89               | 225                      | 9.9                     | Pre-Mitigation  |
| DW 38-L                  | 09/21/88                | 05/04/89               | 225                      | 9.3                     | Pre-Mitigation  |
| DW 47-B                  | 09/21/88                | 03/16/89               | 176                      | 12.5                    | Pre-Mitigation  |
| DW 47-B                  | 09/21/88                | 03/16/89               | 176                      | 24.4                    | Pre-Mitigation  |
| DW 47-L                  | 09/21/88                | 03/16/89               | 176                      | 8.1                     | Pre-Mitigation  |
| DW 47-L                  | 09/21/88                | 03/16/89               | 176                      | 10.4                    | Pre-Mitigation  |
| DW 47-B                  | 04/13/89                | 10/03/89               | 173                      | 1.6                     | Post-Mitigation |
| DW 47-B                  | 04/13/89                | 10/03/89               | 173                      | 1.5                     | Post-Mitigation |
| DW 47-L                  | 04/13/89                | 10/03/89               | 173                      | 1.7                     | Post-Mitigation |
| DW 47-L                  | 04/13/89                | 10/03/89               | 173                      | 1.5                     | Post-Mitigation |

a - pCi/L

b - B - Basement, L - 1st Habitable Level Above Basement

Table 2. Charcoal Canister Measurements for  
Nashville Phase II Basement Houses

| <u>House<br/>ID</u> | <u>Start<br/>Date</u> | <u>Stop<br/>Date</u> | <u>Basement*</u> |      | <u>1st Habitable<br/>Level*</u> |      | <u>Notes</u>    |
|---------------------|-----------------------|----------------------|------------------|------|---------------------------------|------|-----------------|
| DW 01               | 9/13/89               | 9/15/89              | 19.0             | 20.0 | 9.6                             | 9.9  | Pre-Mitigation  |
| DW 01               | 11/6/89               | 11/8/89              | 0.3              | 0.1  | 0.1                             | 0.2  | Post-Mitigation |
| DW 35               | 11/6/89               | 11/8/89              | 9.6              | 9.2  | 6.3                             | 6.1  | Post-Mitigation |
| DW 38               | 4/4/89                | 4/16/89              | 17.5             | 17.8 | 13.6                            | 13.6 | Pre-Mitigation  |
| DW 38               | 8/22/89               | 8/24/89              | 1.3              | 1.1  | 1.0                             | 0.8  | Post-Mitigation |
| DW 47               | 3/14/89               | 3/16/89              | 4.6              | 4.7  | 1.8                             | 1.9  | Pre-Mitigation  |

a - pCi/L

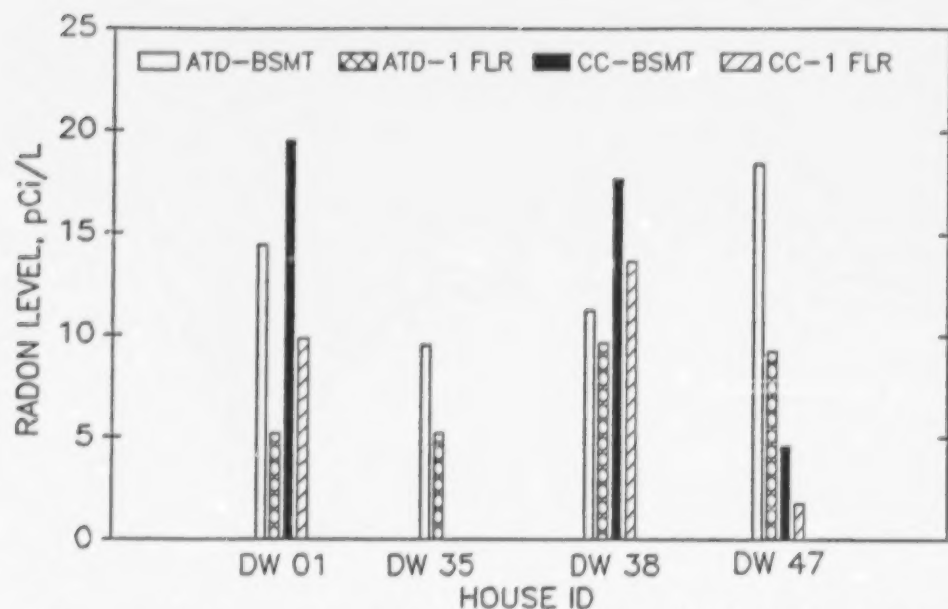


Figure 1. Pre-mitigation ATD and CC results (no CCs at DW 35).

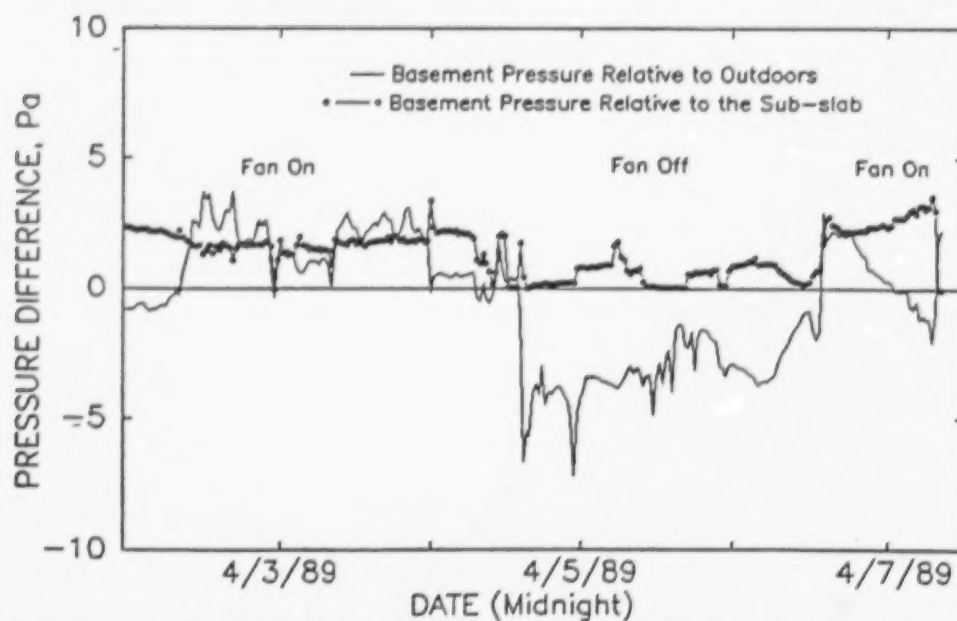


Figure 2.  $\Delta P$  changes as the fan was turned off then back on in DW 47.

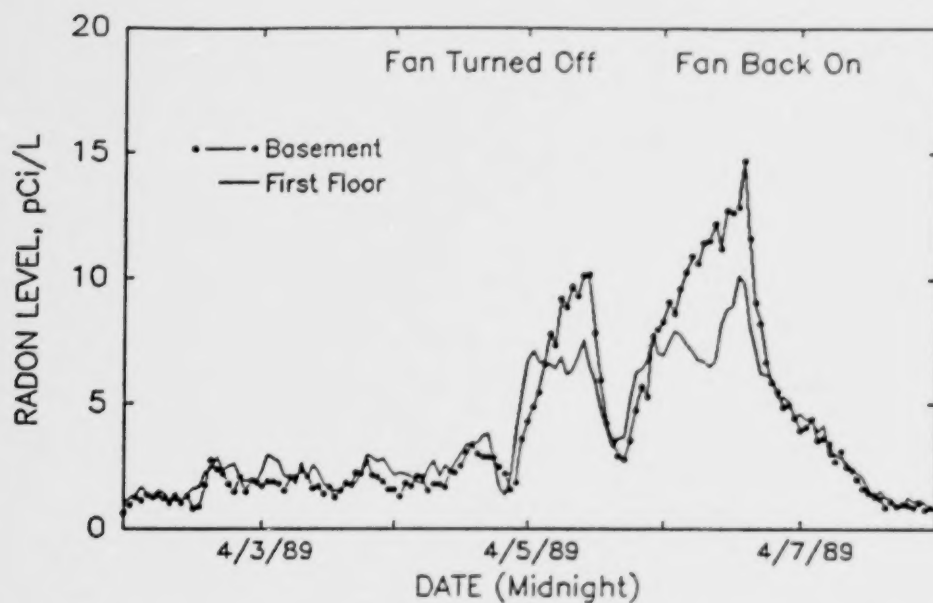


Figure 3. Radon level changes as the fan was turned off then back on in DW 47.

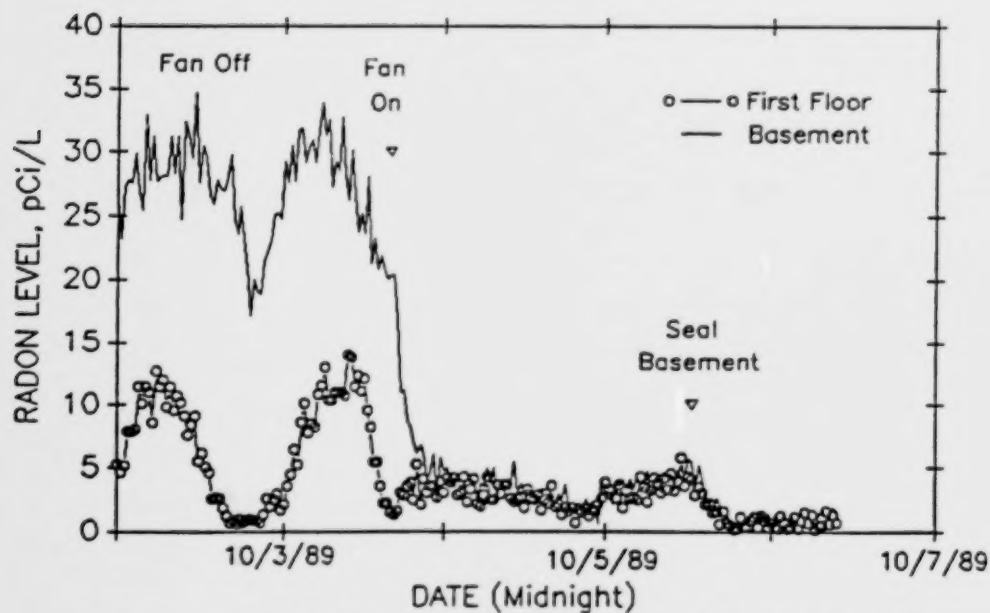


Figure 4. Changes in radon levels as the fan was turned on and as the basement was sealed in DW 01.

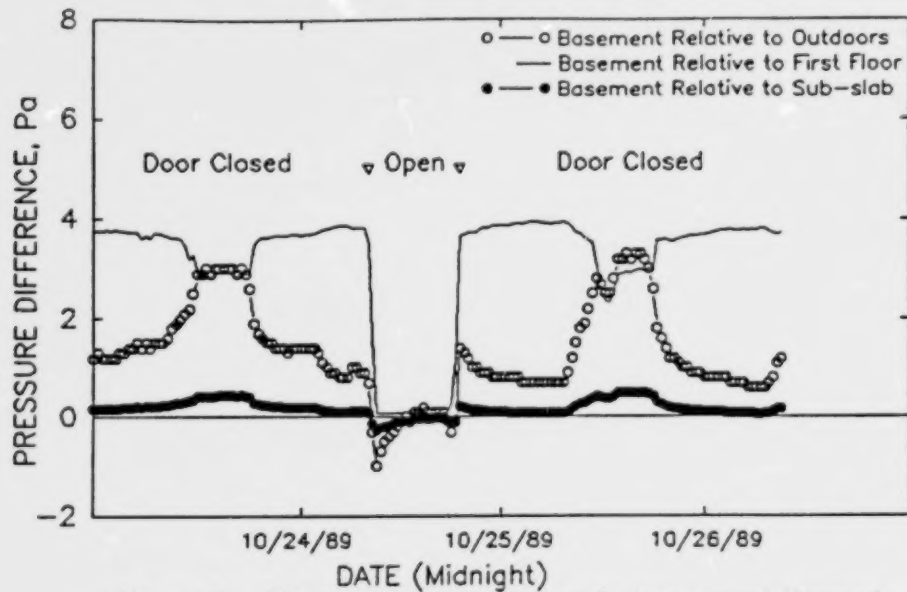


Figure 5. Effects of pressure loss in basement through door left open in DW 01.

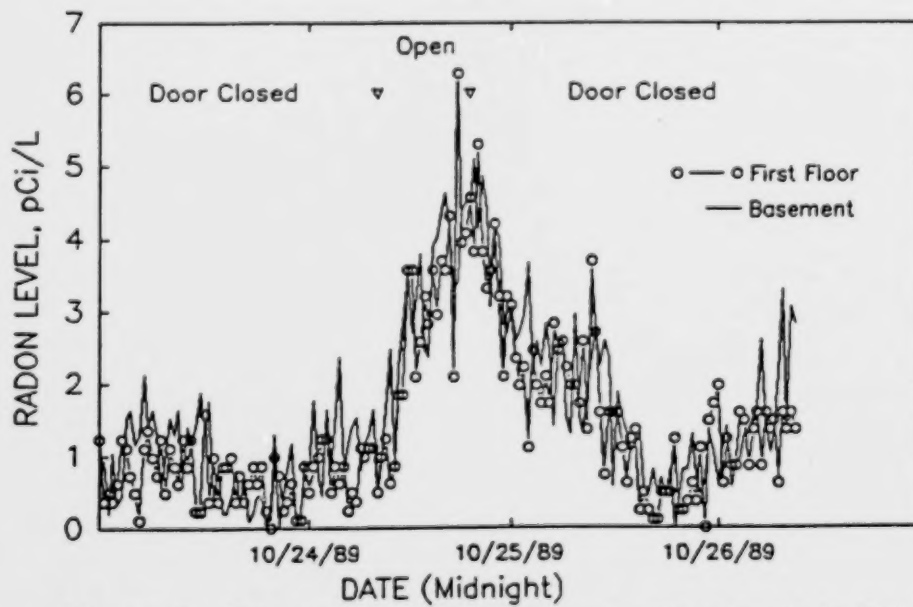


Figure 6. Effects of pressure loss on radon levels in DW 01.

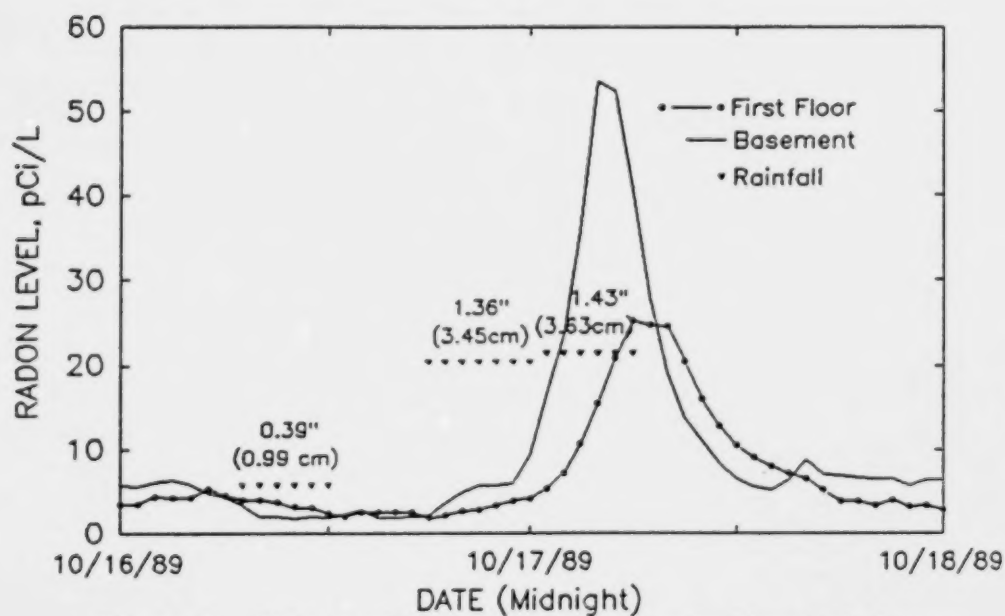


Figure 7. Effects of heavy rainfall on radon levels in house DW 35 mitigated with charcoal adsorption device.